(12) UK Patent Application (19) GB (11) 2 218 853 (13) A

(43) Date of A publication 22.11.1989

(21) Application No 8811756.9

(22) Date of filing 18.05.1988

(71) Applicant
Philips Electronic and Associated Industries Limited

(Incorporated in the United Kingdom)

Philips House, 188 Tottenham Court Road, London, W1P 9LE, United Kingdom

(72) Inventor
Brian John Minnis

(74) Agent and/or Address for Service
R J Boxall
Philips Electronics, Patents and Trade Marks Department, Centre Point, New Oxford Street, London, WC1A 1QJ, United Kingdom

(51) INT CL⁴
H01P 5/18

(52) UK CL (Edition J)
H1W WCAA W7

(56) Documents cited
None

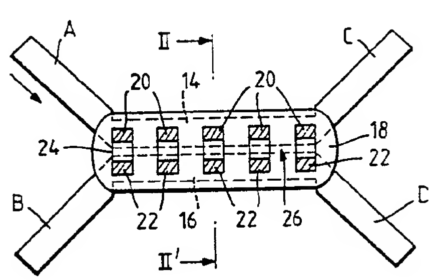
(58) Field of search
UK CL (Edition J) H1W
INT CL⁴ H01P

(54) **Microwave directional coupler**

(57) A microwave directional coupler suitable for fabrication by microstrip or coplanar line methods comprises a substrate (12) on which two coextensive parallel lines 14, 16 are provided. The lines are covered with an insulating layer 18. A series of juxtaposed pairs of metallic pads 20, 22 are provided on the insulating layer 18 above the lines 14, 16. Electrically conductive connections 24 interconnect juxtaposed pairs of the pads 20, 22. The number and disposition of the interconnections determine the coupling ratio and enable the manufacturing tolerances to be relaxed compared to a coupler without capacitors e.g. a Lange coupler.

In a non-shown embodiment (Figure 6) each of the lines has stubs (15, 17) extending laterally outwards. The effect of these stubs is to slow the signal more thereby enabling the lengths of the lines 14, 16 to be substantially 1/3 of the length of a coupler not having stubs.

*Fig. 1.*




At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

GB 2 218 853 A

2218853

Fig. 1.

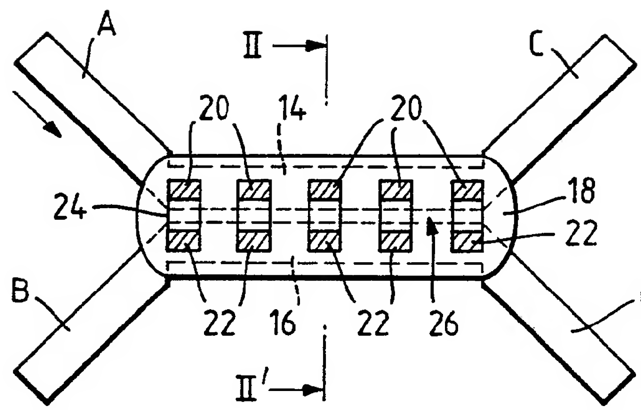



Fig. 2.

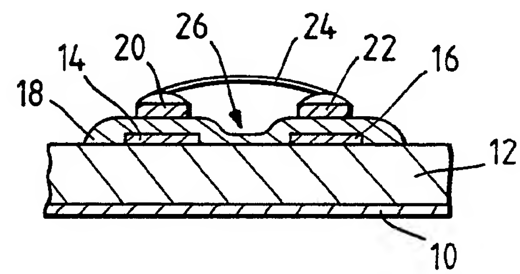



Fig. 3.

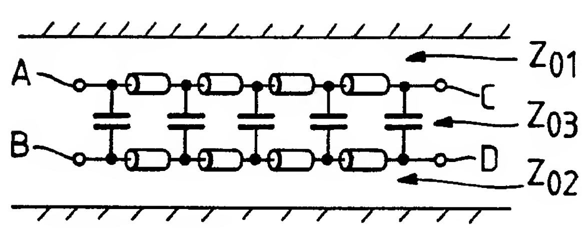



Fig. 4.

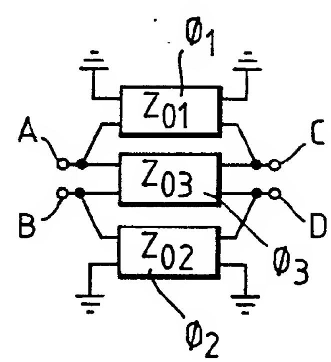


Fig.6.

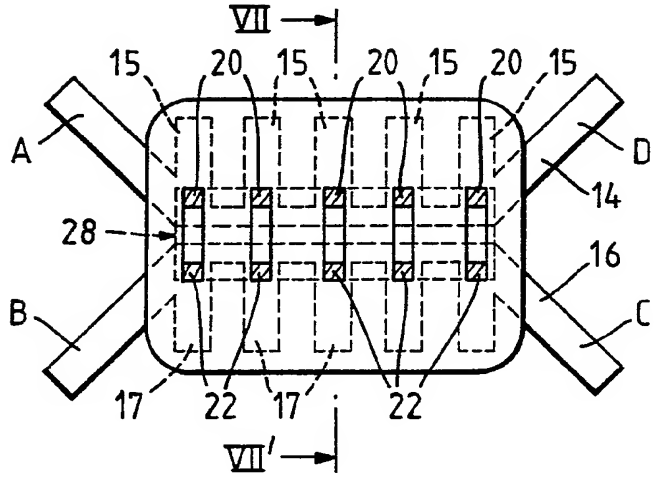



Fig.7.

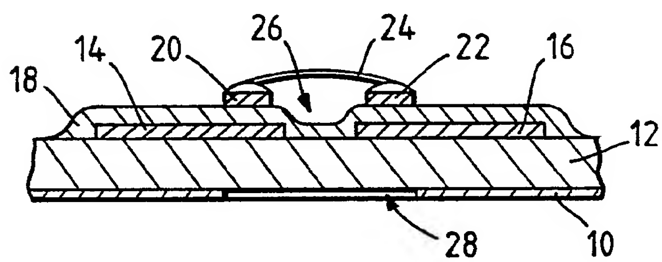
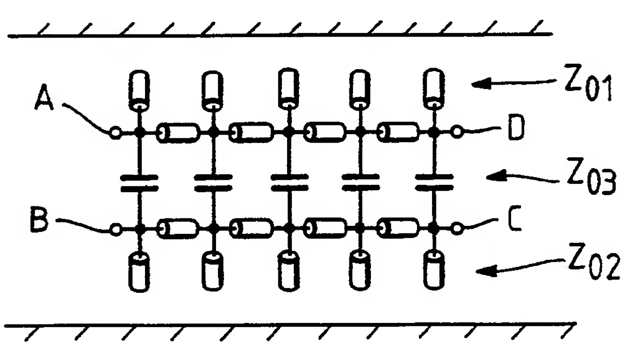



Fig.8.



2218853

Fig.5.

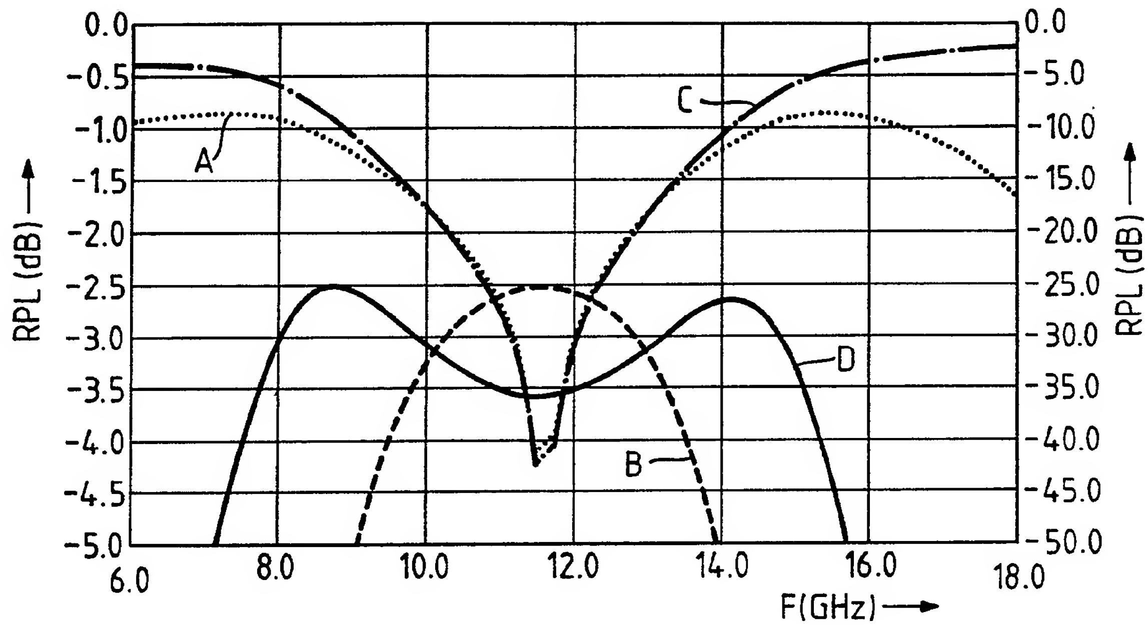
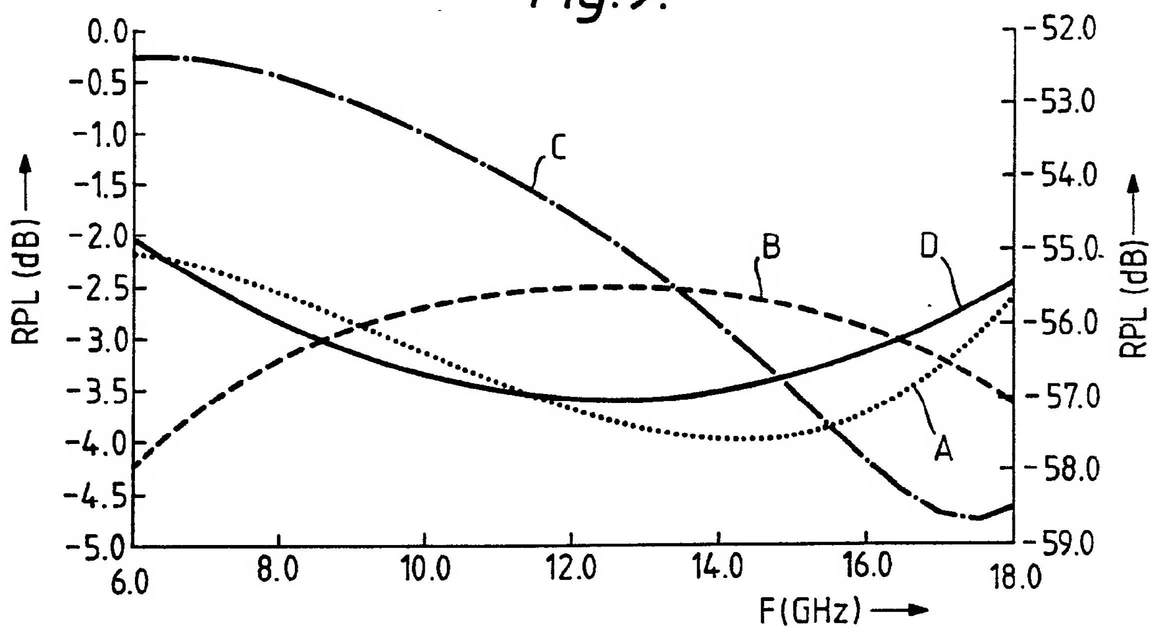



Fig.9.



DESCRIPTION

## MICROWAVE DIRECTIONAL COUPLER

The present invention relates to a microwave directional coupler, particularly a coupler suitable for use in the microwave frequency range say 2 to 20 GHz.

Microwave directional couplers are known per se and an example of a microstrip microwave coupler is disclosed U.S. Patent Specification 3512110. This known coupler comprises a conductive ground plane on which a dielectric substrate is provided. On the substrate a pair of microstrip transmission lines extend along a straight line for one-quarter wavelength of a designed operating frequency. The lines are covered by an overlay dielectric having a dielectric constant equal to the substrate dielectric constant. A coupling strip extends in spaced relation to the microstrip transmission lines over the dielectric and over both lines to confine the electromagnetic fields to within the overlay dielectric and provide improved directivity between the lines. The strip acts as a floating electrode.

Whilst this known coupler is said to enable a microstrip microwave coupler to be fabricated having a uniform electromagnetic field, good directivity and reasonable tolerances in manufacture, it is desired to produce a microwave coupler suitable for printed circuit applications and has a construction which permits the dimensional tolerances to be further relaxed.

According to the present invention there is provided a microwave directional coupler comprising a substrate, two lines provided on the substrate, said lines having coextensive, parallel, closely adjacent portions, a dielectric layer covering at least said portions of the two lines, conductive pads provided on the dielectric layer at locations over said lines and conductive links interconnecting the pads over one of the two lines with juxtaposed pads over the other of the two lines.

The directional coupler made in accordance with the present invention provides coupling ratios between 2 and 3dB. Such a

coupler has applications in microwave amplifiers, mixers and discriminators, especially those in a balanced configuration. The line widths and the width of the gap between adjacent edges of the coextensive portions of the line are not critical. Additionally the alignment of the pads on the dielectric layer is not critical. Such a construction lends itself suitable for fabrication as printed circuits.

In one embodiment of the present invention the lines co-extend for substantially 1/4 of the wavelength of the centre frequency of the operating range. One advantage of such an embodiment is that the input and isolating ports comprise the terminal parts of one of the two coextensive lines and the coupled and through ports comprise terminal parts of the other of the two coextensive lines which simplifies the realisation of the coupler and its use in balanced circuit arrangements.

In another embodiment of the present invention the co-extensive portions of said lines have a plurality of pairs of oppositely extending stubs. A ground plane on the substrate extends beneath said stubs but not under said co-extensive portions of said lines. The length of said coextensive portions is substantially 1/12 of the wavelength of the centre frequency of the operating range thereby offering a considerable saving in size for a particular centre frequency.

The present invention will now be described, by way of example, with reference to the accompanying drawings, wherein:

Figure 1 is a diagrammatic plan view of one embodiment of the directional coupler made in accordance with the present invention,

Figure 2 is a view on the line II-II' of Figure 1,

Figure 3 is an equivalent circuit of the embodiment of Figure 1,

Figure 4 is a simplified view of Figure 3,

Figure 5 is a set of graphs of frequency, F, (GHz) versus relative power level, RPL, (dB) of the signals at respective ports of the directional coupler shown in Figure 1, the power

levels correspond to the power dissipated in 50 ohm terminations and are referenced to the incident power on port A,

Figure 6 is a diagrammatic plan view of another embodiment of the directional coupler made in accordance with the present invention,

Figure 7 is a view on the line VII-VII' of Figure 6,

Figure 8 is an equivalent circuit of the embodiment shown in Figure 6, and

Figure 9 is a set of graphs of frequency (GHz) versus relative power level (dB) of the signals at respective ports of the directional coupler shown in Figure 6 when all the ports are terminated in 50 ohm resistors, powers are referenced to incident power on port A.

In the drawings the same reference numerals have been used to indicate corresponding features in respective embodiments.

The 90 degree hybrid directional coupler shown in Figures 1 and 2 comprises a ground plane 10 provided on one side of a substrate 12 having a high dielectric constant, for example a dielectric constant comparable to that of alumina. A pair of edge-coupled, parallel and co-extensive microstrip lines 14, 16 are provided on the substrate 12. The length of the lines 14, 16 in this illustrated embodiment are equal to a quarter of a wavelength at the centre of the frequency band of operation. The lines 14, 16 are weakly edge-coupled (for example -10 to -15dB). This coupling is increased by a dielectric like $Si_3N_4$ layer 18 of a few microns thick deposited over the lines 14, 16 and by the provision of spaced apart rectilinear gold pads 20, 22 on the layer 18 over the lines 14, 16, respectively. The pads 20, 22 are arranged in juxtaposed pairs which are interconnected by conductive links 24 which, as shown in Figure 2, are spaced from the layer 18 in order to minimise the capacitance to the ground plane 10. The conductive links 24 may be wire bonds (as shown) or may be so-called "air bridges" formed by photolithography. The interconnection of juxtaposed pairs of pads 20, 22 forms parallel plate capacitors and the extra

capacitance created gives the illustrated coupler the required coupling ratio. Thus since the coupling ratio can be adjusted by altering the number of links 24, then the tight tolerances on the dimensions of the lines 14, 16 and the gap 26 between their adjacent edges can be relaxed.

In operation a signal is applied to an input port A and is coupled out through port B. Port C is the isolated port whilst port D constitutes the through port. The provision of the coupled and through ports B and D on the same side of the coupler facilitates its manufacture and application in microwave circuits.

Figure 3 shows an equivalent circuit of the directional coupler shown in Figures 1 and 2 and Figure 4 illustrates a simplified version of Figure 3 expressed in terms of 2 port networks with specified characteristic impedances $Z_{01}$, $Z_{02}$ and $Z_{03}$. In Figures 3 and 4 $Z_{01}$ and $Z_{02}$ represent the characteristic impedances of the lines 14, 16 with respect to the ground plane 10 and are pure even mode elements and $Z_{03}$ represents the characteristic impedance of the artificial transmission line formed by the gap 26 and the capacitors formed by the pads 20, 22.

When discussing coupler behaviour, it is common to speak of even and odd modes. These correspond to the case of two adjacent ports energised by equal amplitude, in-phase signals and two adjacent ports energised by equal amplitude, anti-phase signals, respectively.

A basic formula for defining a coupling ratio, C, is

$$C = \frac{Z_{0e} - Z_{00}}{Z_{0e} + Z_{00}}$$

where $Z_{0e}$ and $Z_{00}$ represent the even and odd mode impedances, respectively. The coupling ratio can be expressed in dB by the expression $C_{dB} = 20 \log_{10} C$. The system impedance $Z_0$ is defined as

$$Z_0 = \sqrt{Z_{0e} \cdot Z_{00}}$$

and

$$Z_{0e} = Z_{01} = Z_{02}$$

$$Z_{00} = \left(\frac{Z_{01}Z_{03}}{2Z_{01} + Z_{03}}\right)$$

The presence of capacitors formed by the interconnected pairs of pads 20, 22 slows down the signal waves propagating between the lines 14 and 16. As a result in Figure 4 the outer boxes $Z_{01}$ and $Z_{02}$ provide phase shifts $\emptyset_1$ and $\emptyset_2$ of -90 degrees at the centre $f_o$ of the frequency band of operation and the box $Z_{03}$ provides a phase shift $\emptyset_3$ of -270 degrees at $f_o$.

Referring to Figures 3 and 4, the following terms ar relevant. $Z_{ogap}$ corresponds to $Z_{03}$ and is the characteristic impedance for waves propogating between the lines 14 and 16 when capacitors are present. $Z_{oslot}$ is the characteristic impedance of the waves propogating between the lines when no capacitors are present.

The length of the coupler L is given by $\beta L = \pi/2$ where

$$\beta = \frac{2\pi}{3 \times 10^N} \text{ fo } \sqrt{\varepsilon \text{reven}}$$

$f_o$ is the centre frequency and reven is the effective dielectric constant for the even mode.

Choosing n, the number of capacitors -1, the capacitor values and $Z_{oslot}$ are given by:-

$$C = 2(\cos\emptyset - b) \Big/ 2\pi f_o \cdot Z_I \sqrt{1-b^2}$$

and

$$1/Z_{oslot} = \sin\emptyset / Z_I \sqrt{1-b^2} - \left(1/2Z_{oe}\right)$$

where

$$\emptyset = \frac{\beta L}{n}, \ \beta = \frac{2\pi f_o}{3 \times 10^{11}} \sqrt{\varepsilon \text{rodd}}, \ b = \cos \frac{3\pi}{2n}$$

and $\varepsilon_{rodd}$ is the odd mode effective dielectric constant.

Figure 5 is a composite graph, the abscissa represents frequency in Gigahertz, the left hand ordinate represents the relative power level (dB) for ports B and D and the right hand ordinate represents the relative power level (dB) for ports A and C, for a directional coupler of the type shown in Figures 1 and

2. Each graph carries the same reference letter designating the function of the port as is used in Figure 1 namely A - input, B - coupled, C - isolated and D - through. In an exemplary embodiment $Z_{0e}$ = 132.26, $Z_{00}$ = 18.90, $Z_{gap}$ = 44.11, $Z_{slot}$ = 159.63, $\varepsilon_{rslot}$ = 5, $\varepsilon_{r}$ even = 6 and a design $f_o$ = 12GHz. It will be noted that the peak in the coupled-out power occurs at a minimum in the through power. The useful fractional bandwidth of the coupler is approximately 50%.

Referring to Figures 6 and 7, the directional coupler shown differs from that shown in Figures 1 and 2 in that the lines 14, 16 have stubs 15, 17, respectively, extending laterally outwards from their outer edges, the stubs 15, 17 being optionally covered by the $Si_3N_4$ layer 18. Additionally a portion 28 of the ground plane 10 beneath the coextensive, parallel lines 14, 16, said portion 28 being outlined in broken lines in Figure 6, is omitted. Finally the length of the coextensive, parallel lines corresponds to approximately 1/12 of the wavelength of the centre $f_o$ of the frequency band of operation.

A practical effect of providing the coupler with the stubs 15, 17 is that they form shunt capacitors which produce a different propagation constant compared to the coupler shown in Figures 1 and 2. The even mode phase velocity is reduced by almost a factor of 3 by these capacitors. As a result the length of the lines 14, 16 can be shorter compared to the Figures 1 and 2 embodiment. The removal of the portion 28 of the ground plane 10 beneath the lines 14,16 is generally desirable in order to realise a desired line impedance. Compared to the embodiment of Figures 1 and 2, the isolated and through ports C and D, respectively, have been interchanged.

Figure 8 shows an equivalent circuit of the embodiment of Figures 6 and 7. The phase shifts Ø1, Ø2 and Ø3 (Figure 4) are in this embodiment all equal to -90 degrees which is the reason for the interchange of the isolated and through ports.

Figure 9 is another composite graph, the abscissa represents frequency in GHz, the left ordinate represents the relative power

level (dB) for ports B and D and the right hand ordinate represents the relative power level (dB) for ports A and C. It will be noted that the shape of the through and coupled graphs are the inverse of each other and acceptable coupler performance is achieved over a wider bandwidth compared to the embodiment of Figures 1 and 2, a peak of 2.5dB occuring at $f_o$ = 12.5GHz. The coupler used to provide the graphs was only a theoretical example. A practical design would use fewer stubs. The theoretical example comprised 25 pairs of stubs 15, 17 with a pitch, l between them of 0.0362 mm and an overall length, L, = nl = 0.904nm where n is the number of pairs of stubs. Additionally $\varepsilon_r$ eff slot = 5 and $\varepsilon_s$ eff even = 6.

The embodiment of Figures 1 and 2 is capable of being fabricated in microstrip whereas that of Figures 6 and 7 is capable of being fabricated in microstrip and in coplanar line. In the case of coplanar line fabrication it is not necessary to provide a conductive ground plane.

From reading the present disclosure, other modifications will be apparent to persons skilled in the art. Such modifications may involve other features which are already known in the design, manufacture and use of the directional couplers and component parts thereof and which may be used instead of or in addition to features already described herein. Although claims have been formulated in this application to particular combinations of features, it should be understood that the scope of the disclosure of the present application also includes any novel feature or any novel combination of features disclosed herein either explicitly or implicitly or any generalisation thereof, whether or not it relates to the same invention as presently claimed in any claim and whether or not it mitigates any or all of the same technical problems as does the present invention. The applicants hereby give notice that new claims may be formulated to such features and/or combinations of such features during the prosecution of the present application or of any further application derived therefrom.

CLAIM(S)

1. A microwave directional coupler comprising a substrate, two lines provided on the substrate, said lines having coextensive, parallel, closely adjacent portions, a dielectric layer covering at least said portions of the two lines, conductive pads provided on the dielectric layer at locations over said lines and conductive links interconnecting the pads over one of the two lines with juxtaposed pads over the other of the two lines.

2. A coupler as claimed in Claim 1, wherein the conductive pads are square.

3. A coupler as claimed in Claim 1 or 2, wherein the pads comprise gold.

4. A coupler as claimed in Claim 1, 2 or 3, wherein the pads have a width less than that of the lines.

5. A coupler as claimed in any one of Claims 1 to 4, wherein the substrate comprises alumina.

6. A coupler as claimed in any one of Claims 1 to 5, wherein the conductive links comprise wire links.

7. A coupler as claimed in any one of Claims 1 to 5, wherein the conductive links comprise air bridges.

8. A coupler as claimed in any one of Claims 1 to 7, wherein said lines co-extend for substantially 1/4 of the wavelength of the centre frequency of the operating range.

9. A coupler as claimed in Claim 8, wherein terminal parts of one of the two coextensive portions are input and isolating ports and terminal parts of the other of the two coextensive portions are coupled and through ports.

10. A coupler as claimed in any one of Claims 1 to 9, further comprising ground plane on a surface of the substrate remote from the two lines.

11. A coupler as claimed in any one of Claims 1 to 7, wherein said co-extensive portions of said lines have a plurality of pairs of oppositely extending stubs.

12. A coupler as claimed in Claim 11, wherein there is a

ground plane which extends beneath said stubs but not under said co-extensive portions of said lines.

13. A coupler as claimed in Claim 11 or 12, wherein the length of the two coextensive portions of said lines is substantially 1/12 of the wavelength of the centre frequency of the operating range.

14. A microwave directional coupler constructed and arranged to operate substantially as hereinbefore described with reference to and as shown in the accompanying drawings.

Published 1989 at The Patent Office, State House, 66/71 High Holborn, London WC1R 4TP Further copies may be obtained from The Patent Office. Sales Branch, St Mary Cray, Orpington, Kent BR5 3RD. Printed by Multiplex techniques ltd, St Mary Cray, Kent, Con. 1/87